Modelling X-ray beacons in curved space time

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in collaboration with

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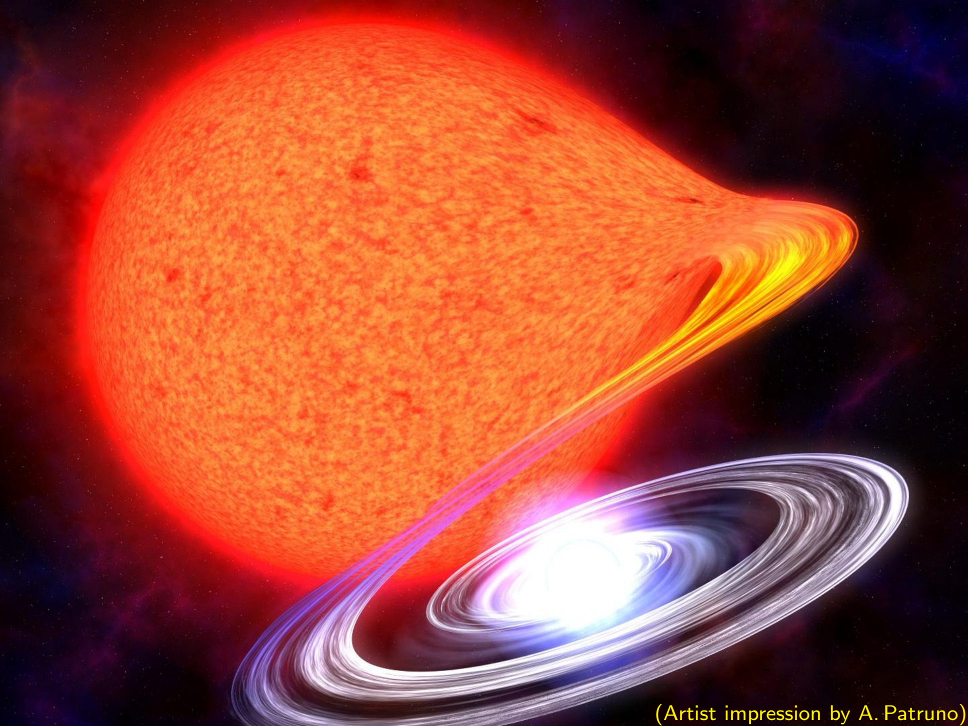
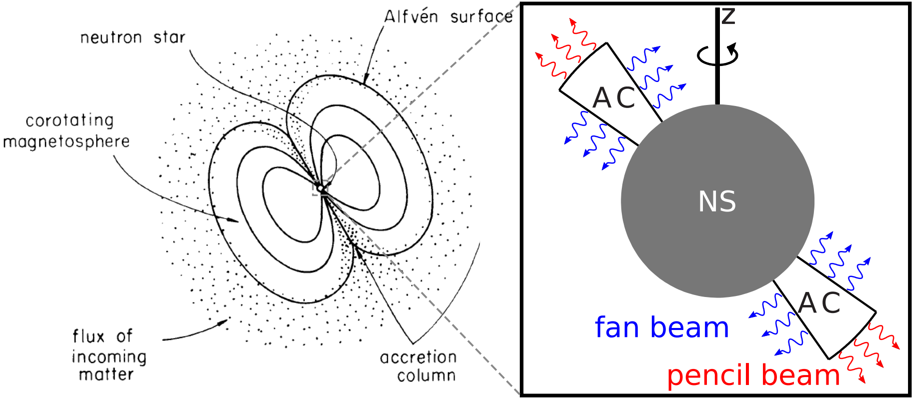


(Artist impression by A. Patruno)

Accreting neutron stars



(adapted from Lamb et al., 1973)

compact object

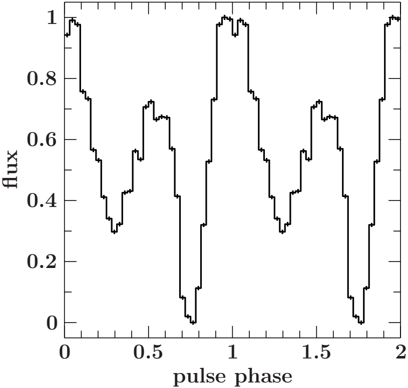
Mass: $1 - 3\ M_\odot$

Radius: $8 - 20$ km

highly magnetized

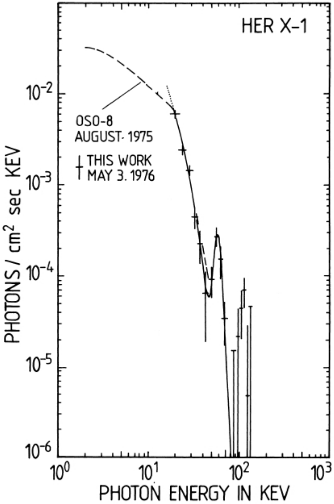
B-field: $B \sim 10^{12}$ G

Observables



(priv. comm M. Kühnel)

pulse profile

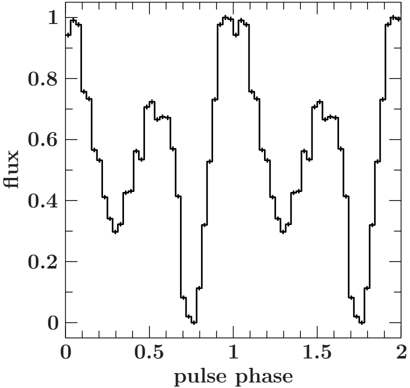


(Trümper et al., 1978)

cyclotron line

Task

Modeling **pulse profiles** of **accreting neutron stars**



(priv. comm M. Kühnel)

Tool needed which accounts for **relativistic effects** while allowing

- arbitrary geometries for the emission regions
- arbitrary emission profiles

light bending

Schwarzschild metric (spherical coordinates)

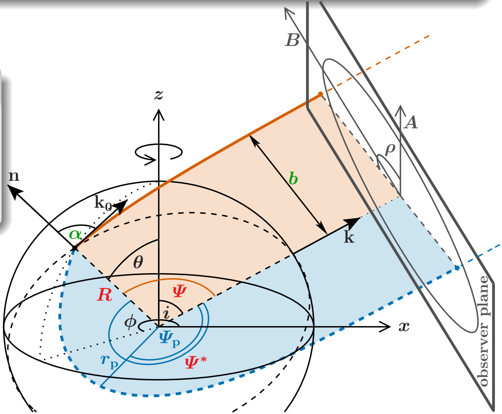
$$ds^2 = -\left(1 - \frac{2M}{r}\right) dt^2 + \left(1 - \frac{2M}{r}\right)^{-1} dr^2 + r^2 \left(d\theta^2 + \sin^2\theta d\phi^2\right)$$

Photon trajectory to observer

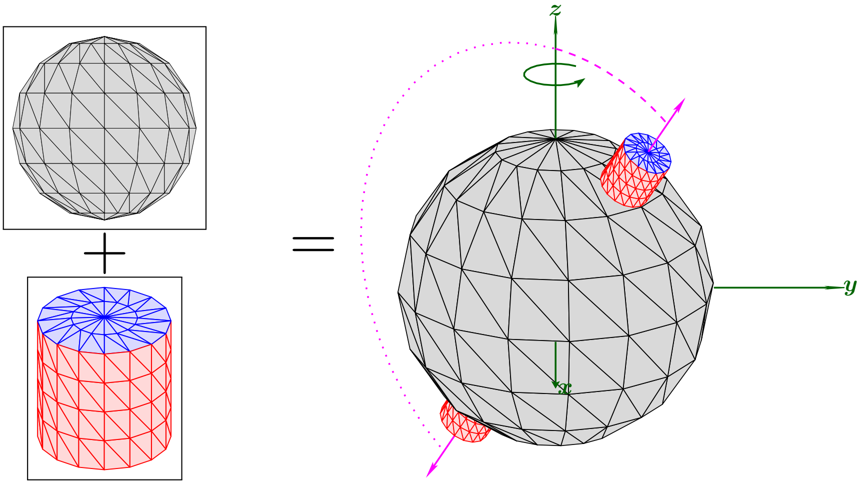
$$\Psi(R) = \int_R^\infty dr \frac{1}{r^2}\left[\frac{1}{b^2} - \frac{1}{r^2}\left(1 - \frac{2M}{r}\right)\right]^{-\frac{1}{2}}$$

observed flux

$$dF = I \cdot d\Omega(\Psi, b)$$

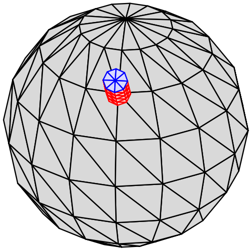


Sample geometry of the emitting surface with small surface elements

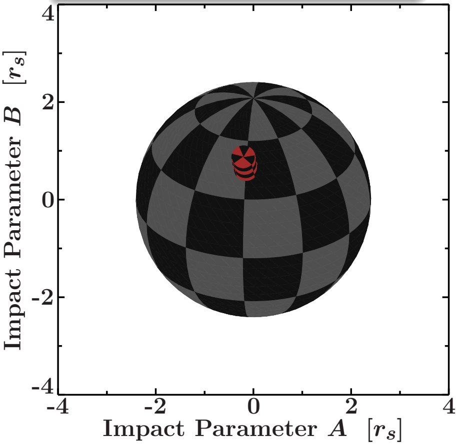


light bending

geometry



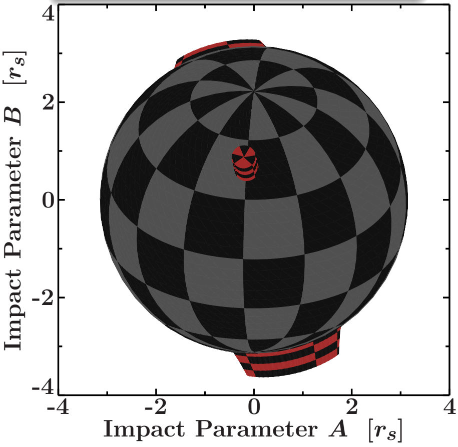
geometrical projection



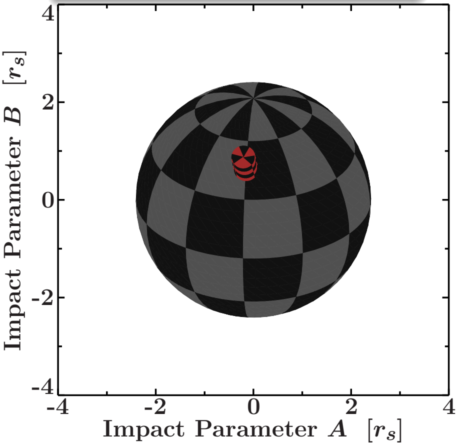
light bending

geometry

relativistic projection



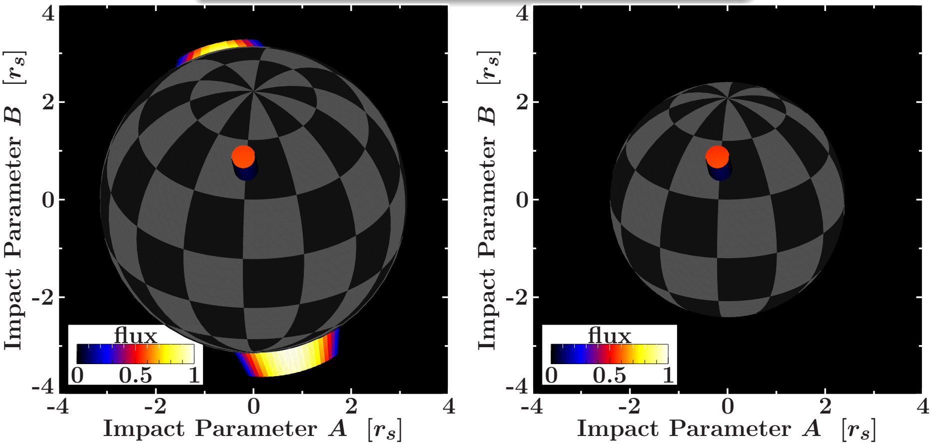
geometrical projection



light bending

geometry + emission profile

emission profile: $I \propto 1 + 2 \cdot \cos(\gamma)$



light bending

geometry + emission profile → observed flux

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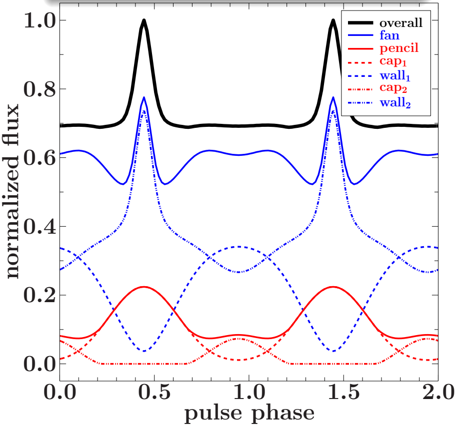
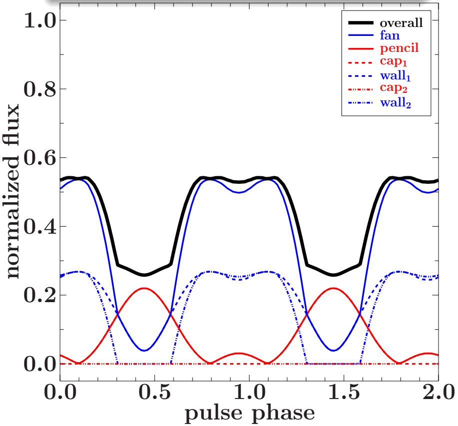
relativistic/geometrical case ?



relativistic/geometrical case ?



light bending

geometry + emission profile → observed flux

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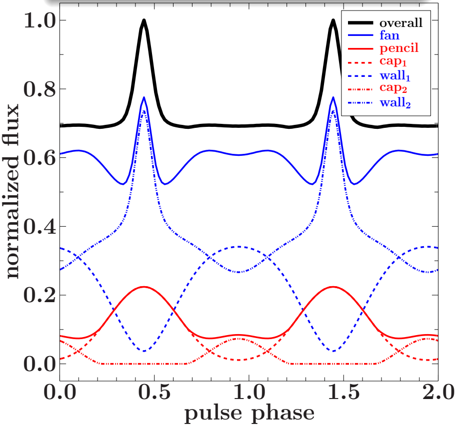
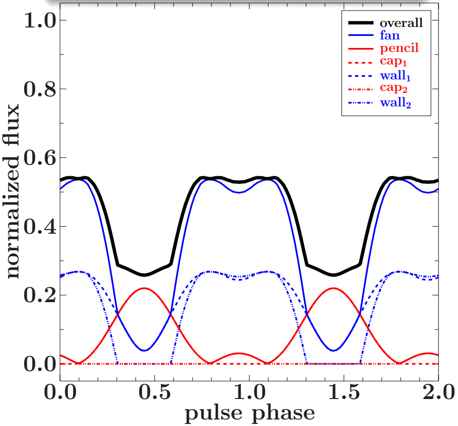
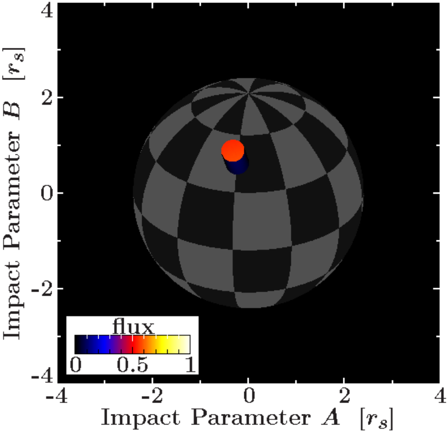
relativistic/~~geometrical~~ case !

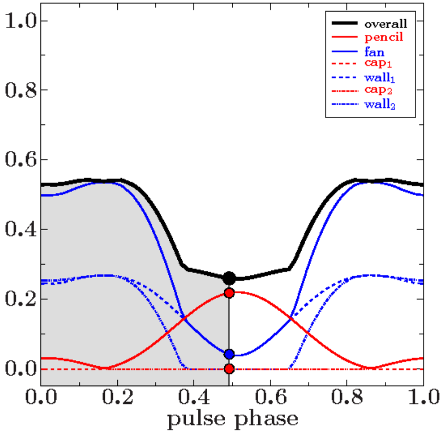


~~relativistic~~/**geometrical** case !



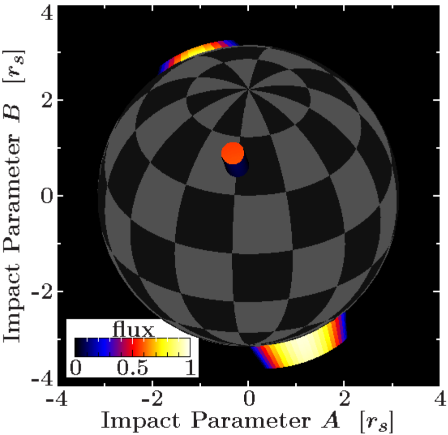
light bending: geometry + emission profile → observed flux

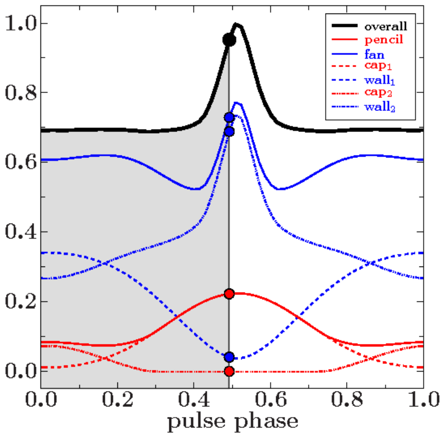




light bending

geometry + emission profile → observed flux





light bending model

We now have a modular model to obtain the observed flux of an accreting neutron star accounting for

- relativistic effects
- arbitrary geometries for the emission regions
- arbitrary emission profile

model parameters

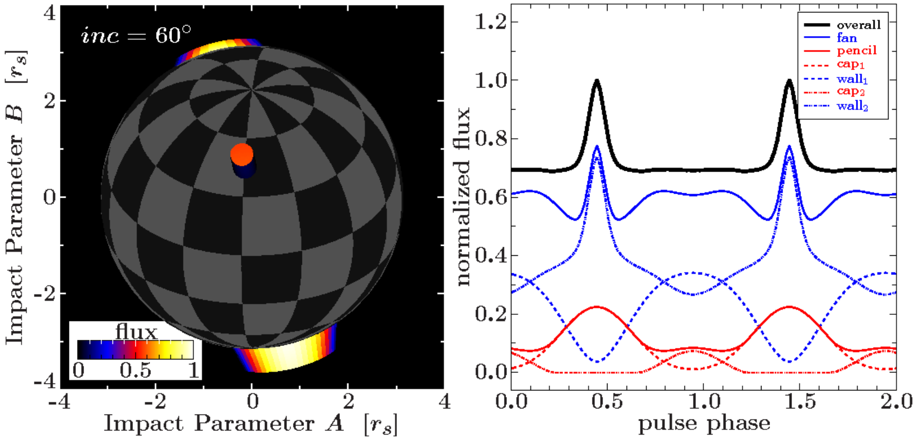
neutron star:
M_{NS}, R_{NS}, f

emission region, e.g., accretion column:
i_{AC_1}, ϕ_{AC_1}; R_{AC_1}, H_{AC_1}
i_{AC_2}, ϕ_{AC_2}; R_{AC_2}, H_{AC_2}
$\ldots$

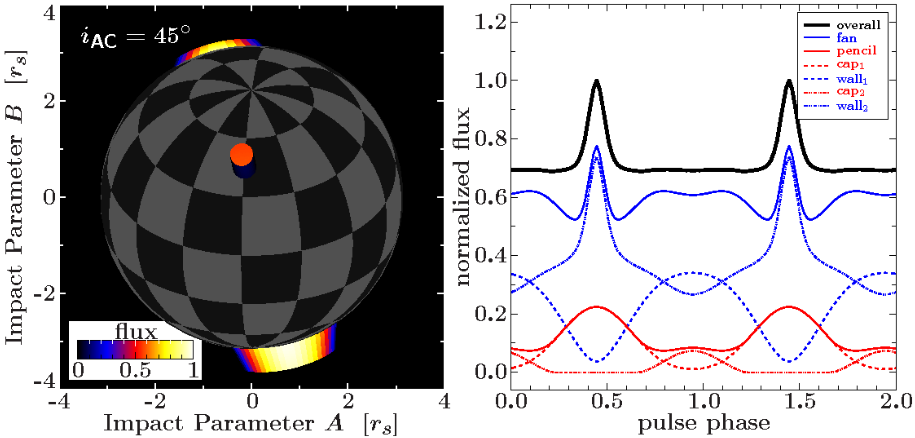
observer:
inc

beam pattern:
$I_E(\vec{R}, \vec{k}_0, \ldots)$

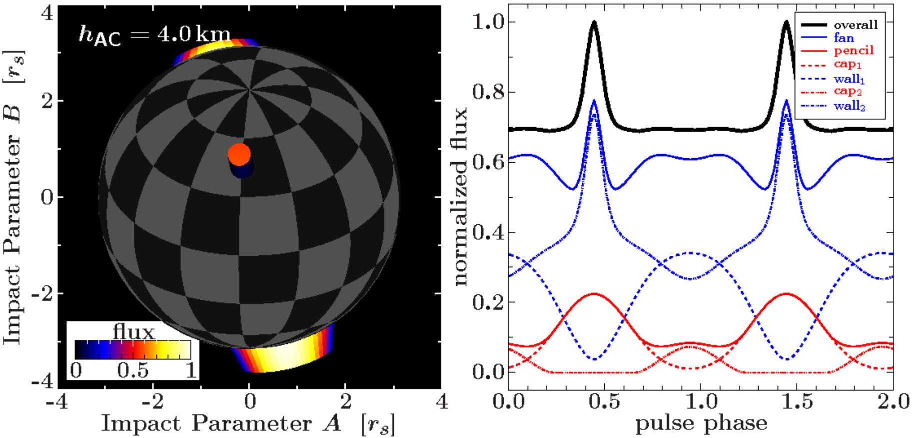
Impact of the observers inclination



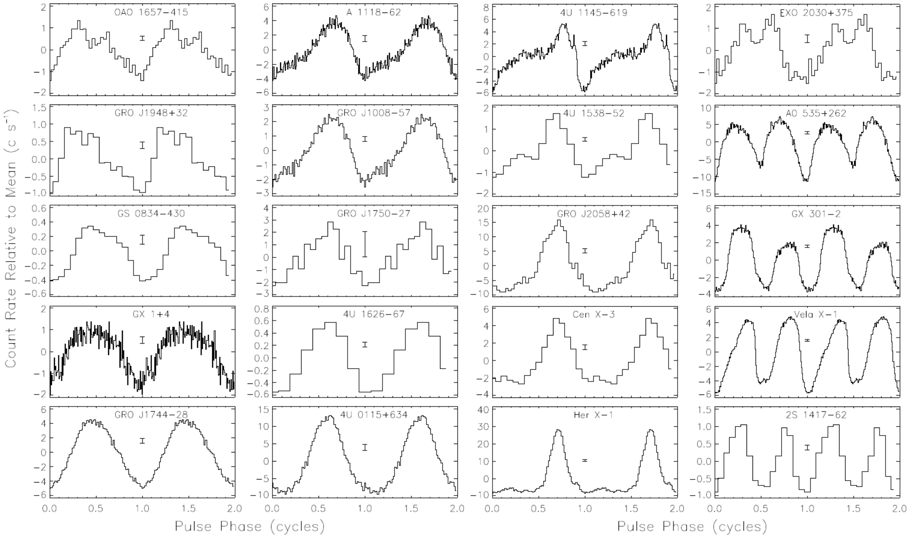
Impact of the inclination of the magnetic field



Impact of the height of the accretion column

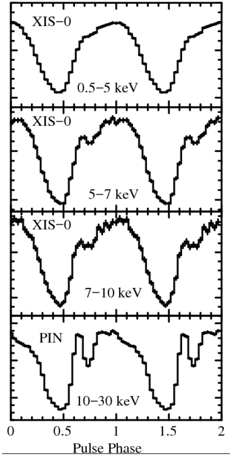


Outlook

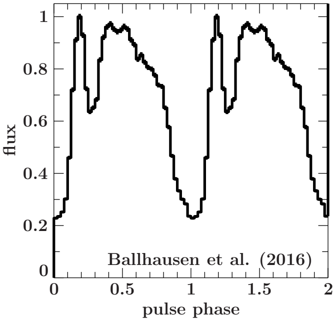


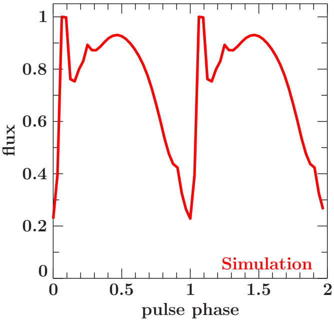
(Bildsten et al., 1997)

Pulse profile of KS 1947+300



(Epili et al., 2016)





The narrow peak can be explained with strong light bending while changes in energy relate to changes in height

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